10.0 RI CONCEPTUAL SITE MODEL SUMMARY

The CSM for the Portland Harbor Study Area is presented in this section. A CSM is a representation of an environmental system and the biological, physical, and chemical processes that affect the transport of contaminants from sources through environmental media to human and ecological receptors in the system. This section presents a CSM for the Portland Harbor RI/FS Site that draws on and synthesizes supporting information presented previously in this RI. Section 10.1 presents a Study Area-wide overview of the physical setting; contaminant distribution in sediments; contamination sources identified to date; external loading and internal fate and transport mechanisms; and human health and ecological receptors, ~~risk drivers~~ and exposure pathways and ~~/~~scenarios (USEPA 2005a).

Section 10.2 is a CSM presentation for the specific indicator contaminants described in Section 5, consistent with EPA (2005a) guidance. It includes a series of contaminant-specific maps of the Study Area's abiotic and biotic data sets that illustrate relationships between the observed contaminant distributions and known and likely historical and current sources and pathways. These displays are intended to provide a picture of the distribution, transport, and fate of contaminants in the Study Area across a range of physical, chemical, and biological processes, as well as potential sources.

The ~~general~~ objective of this CSM is to illustrate our understanding of the sources and fate and transport mechanisms that determine the observed distribution of individual contaminants in affected abiotic and biotic media across the Study Area, based on the information and data collected, compiled, and evaluated in this RI.

10.1 SITE CONCEPTUALIZATION

A pictorial representation illustrating the major elements of the CSM (sources, pathways, fate and transport mechanisms, and human and ecological receptors) for the Portland Harbor Study Area is shown in Figure 10.1-1, while Figure 10.1-2 presents a graphical conceptualization of the sources, release mechanisms, transport media, and exposure media of the CSM. The detailed human health and ecological CSMs for the Portland Harbor Site are summarized in Appendix F, Figure 3-1 (also RI Section 8, Figure 8.2-1) and Appendix G, Attachment 2, Figure 1 (also RI Section 9, Figure 9.1), respectively, and focus on exposure routes and receptor groups.

10.1.1 Physical Setting and Sediment Dynamics

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The Portland Harbor Study Area (RM 1.9 to 11.8 of the Willamette River) is located at the downstream end of the lower Willamette River, which extends from the Willamette Falls at RM 26 to its convergence with Columbia River at RM 0. In its natural, undisturbed state, the Study Area reach was relatively shallow and meandering, surrounded by uplands, forested wetlands, and floodplains. Over the last century, much of the original riverbed has been dredged and the adjacent riverbanks have been filled, stabilized, and/or engineered for commercial, industrial, and marine operations with riprap, bulkheads, and overwater piers and docks. The extensive physical alteration and the associated anthropogenic activities as well as upstream river-stage control through the construction and management of dams, have resulted in a river reach that little resembles its pre-industrialized character in terms of hydrodynamics, sediment processes, and ecological habitat.

The effect of the multipurpose dams has been to ~~generally~~ dampen the flows during seasonal and storm events. The Columbia river also plays a role in the flow dynamics of the Willamette River. In Spring, high flows in the Columbia River can increase the hydraulic head at the confluence causing the Willamette River to be detained and reduce flows until water levels drop in both river systems. Tidal action also compounds the hydrology and interplay of the two rivers, and affects the Willamette River upstream as far as Portland Harbor and beyond. These tidal fluctuations can result in short-term flow reversals (i.e., upstream flow) in Portland Harbor during times of extremely low river stage combined with a large variation in tide levels, which can occur in late summer to early fall.

Within the Study Area, there are distinct reaches that share similar hydrodynamic and sediment bed characteristics (see Section 3.1.5). Because of the affinity of both organic and inorganic contaminants to be associated with particulates, the transport and fate of sediments in the Study Area strongly affects the distribution of most contaminants. The primary factors controlling river flow dynamics, sediment deposition and erosion, and riverbed character appear to be the river cross-sectional area and navigation channel width. The upstream boundary of the Study Area to Willamette Falls is markedly narrower, more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. The river widens as it enters the Study area and becomes increasing depositional, especially in the western portion of the the river~~nearshore area~~, until river mile seven. From about river mile seven to river mile five, the river and navigation channel narrows again, and this reach is dominated by higher energy environments with little deposition. From river mile five to about river mile two, the river widens again and becomes depositional, especially in the eastern portion of the river~~nearshore area~~. Immediately downstream of the Study Area, the river narrows as it turns and converges with the Columbia River. Multnomah Channel exits at RM 3, considerably reducing discharge to the Columbia River.

Long-term net sedimentation rates in the Study Area were estimated ~~for~~ based on time-series bathymetric surveys. The measured riverbed elevation changes over the seven-year period from 2002 to 2009 and illustrates a pattern of general shoaling in the relatively wide reaches from RM 7 to 10 and RM 2 to 5, and no change or scour in the higher energy, narrow reaches upstream of RM 10 and between RM 5 and 7 (Map 3.1-7) The maximum net sedimentation accumulation rates (exceeding 30 cm/yr in some places) occurs in the navigation channel ~~between RM 1.5 and 3~~, between RM 8 and 10 and in the upstream borrow pits at RM 10.5 and 10.9.

Commented [GR2]: This concept from paragraph EPA comments in more appropriate for Section 10.2 on page 10-3 is important to note in the context of the sediment transport discussion.

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~~Shoaling on a similar scale along~~ T~~t~~he western half of the navigation channel~~,~~ from RM 8 to 10~~, is evident from the 2002 to 2009 bathymetric change data set; this area~~ has historically required regular maintenance dredging. Bathymetric change data from 2002 to 2009 in the downstream channel shoaling area, which begins at RM 2.8 and extends downstream towards RM 1.5~~.~~ showed a maximum sediment rate of about 18 cm/yr at RM 2 over this seven-year time frame. The decrease in net sedimentation rates between upstream and downstream channel shoaling areas is consistent with a single major source of sediments that enter the Study Area from upstream and settle out or are trapped in depressions and shoaling areas as they move downstream.

Commented [GR6]: I think this observation should be pointed out given it's relevance to sediment loading to the system.

Bathymetric change data, SPI observations (SEA 2002b), and the radioisotope sampling (Anchor 2005) data indicate that sediments do not generally accumulate in nearshore areas at the rates noted above for ~~as they do~~ the shoaling areas in in the main channel. ~~environment.~~ Nonetheless, many nearshore areas exhibit fine-grained sediment~~s~~ accumulation based on both bathymetric change data and SPI interpretation. The bathymetric change data (Map 3.1-7) shows that some nearshore areas (RM 2-3W, RM 4-, 5, RM 7-8, RM 8-9W) show net sediment accumulation exceeding 30 cm from 2002 to 2009. In other areas, such as RM 9-11E, areas within Swan Island Lagoon and Willamette Cove, RM 6-7W, and RM 5-7E, little net elevation change and/or small-scale scour was observed.

10.1.2 Contaminant Distribution

This section provides a brief overview of the overall distribution of contaminants in Study Area sediments, the CSM data presentations that follow in Section 10.2 focus on the distributions of each of the individual indicator contaminants. Contaminant concentrations in sediment and other media are presented in Panels 10.2-1 through 10.2-15. Sediment concentrations are grouped into concentration ranges based on the data distributions (see Section 5.2) and are presented in Thiessen polygons. Based on examination of the contaminant distribution trends some general patterns emerge among subsets of different contaminants that reflect Study Area fate and transport processes, as well as the relative importance of regional versus Study Area sources. These ~~general~~ patterns are discussed below.

Sediment contaminant concentrations are greatest in nearshore areas. Concentrations of contaminants are generally higher in localized nearshore and off-channel areas as compared to sediments in the navigation channel, Multnomah Channel, and downstream areas.

Organic contaminant concentrations are ~~generally~~ greater in subsurface sediments. Concentrations of organic contaminants tend to be higher in subsurface sediments than in surface sediments. Concentrations of total PCBs, DDx, total PAHs, hexachlorobenzene, total chlordanes, aldrin and dieldrin, gamma-hexachlorocyclohexane (Lindane), lead, and TBT are higher in subsurface than in

Commented [Int7]: Some non-IC contaminants were added to these lists per discussion w/EPA on 12/1 surface sediments, indicating that historical inputs were likely greater than current inputs. In contrast, arsenic, copper, chromium, mercury, and zinc do not have large concentration ranges and generally show similar levels in surface and subsurface sediments.

Regional inputs exhibit uniform concentrations across the area. Contaminants that may be derived predominantly from regional or upstream inputs show widespread surface sediment distributions without distinct, isolated areas of higher concentrations. Examples of this are arsenic,chromium (Panels 10.2-9A–B and 10.2-12A–B), and mercury (Appendix D1.2-46 and D1.2-47) which occur at relatively low concentrations throughout the Study Area, and no strong concentration gradients are apparent.

Areas of high concentrations are present throughout the Study Area and generally are associated with known upland sources. A number of contaminants exhibit relatively high sediment concentrations in distinct areas offshore of known or likely sources. These areas are separated by large areas with relatively lower concentrations lacking obvious concentration gradients. Contaminants that exhibit this ~~general~~ trend include total PCBs, TCDD, BEHP, butylbenzyl phthalate, pentachlorophenol, hexachlorobenzene, total chlordanes, Lindane, copper, zinc, and TBT.

Some contaminants have areas of high concentrations that are more common in the lower (downstream) half of the Study Area. DDx and total PAHs exhibit elevated concentrations at locations adjacent to known upland sources. Concentrations of these contaminants ~~i~~ are elevated relative to upstream concentrations.

Concentrations of certain metals are correlated to sediment grain size: A comparison of metals concentrations to the distributions of percent fines in the Study Area shows that where sediments are comprised of less than 40 percent fines, chromium and copper concentrations are relatively low (above RM 10, between RM 5 and 7, and in the Multnomah Channel; compare Map 3.1-2 with Panels 10.2-12A and 10.2-10A). A similar, but less pronounced, correspondence exists between sandy sediments and zinc concentrations (Panel 10.2-11A).

Multiple contaminants co-occur: Several locations within the Study Area have relatively high surface sediment concentrations of more than one contaminant. Some of these areas and the co-occurring contaminants are as follows:

- **RM 11E:** total PCBs, dioxins/furans, DDx, chromium, copper
- **RM 9.7W:** total PCBs, dioxins/furans, BEHP, zinc
- **RM 8.7–9.3W:** total PCBs, dioxin/furans, total PAHs, total chlordanes, copper, mercury, nickel, and zinc
- **RM 8.3W:** total PCBs, total PAHs, BEHP, total chlordanes, dieldrin, lead, copper

- **Swan Island Lagoon:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, chromium, copper, zinc, , TBT
- **RM 6.8–7.5W:** dioxins/furans, DDx
- **RM 6.7–6.8E:** total PCBs, dioxins/furans, copper
- **RM 5.6–5.7E:** dioxins/furans, total PAHs, total chlordanes, Lindane, chromium, copper, lead, mercury, zinc,
- **RM 4.3–4.5E:** total PCBs, dioxins/furans, total PAHs, total chlordanes, zinc
- **International Slip:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, chromium, copper, lead, zinc, ~~,~~ TBT.

This degree of contaminant co-occurrence in specific Study Area locations reflects the history of upland site development, including waste and stormwater conveyance systems and industrial and commercial activities, as described in Section 4 and summarized in Section 10.1.3 below.

10.1.3 Site Sources

The following is a summary of information presented in Section 4 on the ~~general~~ nature of historical and current sources and associated pathways to the Study Area.[1] Although this and earlier sections identify many specific sources of contamination, this RI report does not present an exhaustive list of current or historical sources of contamination. Identification and evaluation of potential sources is still ongoing. All historical sources may never be known, and current sources likely will continue to be discovered into the future. However, sufficient information about likely significant historical and current sources is available for preparation of the FS.

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10.1.3.1 Historical

Historical sources dating back to the early 1900s contributed to the majority of the observed contaminant distributions in sediments within the Study Area. This is reflected in the extent and degree of subsurface sediment contamination as discussed in the previous section. Nearly all the identified chemical pathways have an historical component.

In the early 1900s, rivers in the United States were generally used as open sewers, which was also true for the Willamette (Carter 2006). Untreated sewage, contaminated stormwater runoff from various land uses, as well as process water from a variety of industries, including slaughterhouses, lumber mills, paper mills, and food processors,

Commented [Int9]: These details are important for historical context.

[1] *The source information presented in this Portland Harbor RI report is a compilation of public information available from site owners and operators and from DEQ, and is based upon information provided through September 2010, and DEQ's September 2010 Source Control Milestone Report. Source information will be updated in the Portland Harbor FS report.*

was discharged directly into the river, as were pollutants from less conspicuous (non-point) sources, including agricultural fields, oil spills, rubber and oils, and garbage dumps. With the ~~general~~ exception of manufactured gas operations and bulk fuel storage, which began in the late 1800s, most chemical manufacturing and use began in the 1930s.

Commercial and industrial development in Portland Harbor accelerated prior to World War I and again during World War II. These industrial operations and their associated COIs are discussed in more detail in Section 4 and summarized here:

- **Ship Building, Dismantling, and Repair.** VOCs, SVOCs, PAHs, PCBs, TPH, copper, zinc, chromium, lead, mercury, phthalates, and butyltins are common sediment contaminants associated with shipyards. Approximate areas of former shipyards include RM 4E, 5.6E, 7E, 7.4E, Swan Island, RM 9W, 10W, and 11E. Ship building continues at a much smaller scale in Portland Harbor today, with most work focused on ship maintenance and repair.
- **Wood Products and Wood Treating.** COIs typically associated with sawmills include metals, TPH, and PAHs. In addition to these COIs, plywood manufacturing could include VOCs and SVOCs, as well as possibly pesticides and fungicides (Eaton et al. 1949; U.S. Forest Service 1964; Moore and Loper 1980; Stellman 1998). Lumber mills and wood treatment facilities operated at various locations within the Study Area historically. McCormick& Baxter, a large wood-treating facility, was located at RM 6.9–7.2E. COIs associated with wood treatment include creosote/diesel oil mixtures, PCP, and a variety of water- and ammonia-based solutions containing arsenic, chromium, copper, and zinc (EPA 2006d). PCP wood treatment products routinely contain dioxin/furans as contaminants, and these are an additional COI of wood treatment facilities (EPA 2004b). Many other lumber mills and plywood manufacturers were found throughout the Study Area, including Linnton Plywood, St. Johns Lumber (which operated on the present-day Crawford Street and BES WPCL sites), Kingston Lumber, and former mills in Willamette Cove.
- **Chemical Manufacturing and Distribution.** Chemical plants within the Study Area (RM 6.8–7.5W) that manufactured pesticides and herbicides were in place as early as 1941. Rhone Poulenc and Arkema were the two primary pesticide and herbicide manufacturers in this area. Several distributors of chemicals have existed at the site, including Univar and Mt. Hood Chemical. COIs typically associated with these operations include pesticides, herbicides, VOCs, dioxins/furans, and metals (especially arsenic).
- **Metal Recycling, Production and Fabrication.** Metal salvage and recycling facilities operated at RM 4E, 5.8W, 7.3W (Schnitzer-Doane Lake), 8.5W (Calbag/Acme), 8.9W (Gunderson – Former Schnitzer Steel auto dismantling), and 10W (Calbag) in the Study Area, and several scattered locations upriver COIs commonly found in waste streams from metal recycling facilities include VOCs, TPH, PCBs, phthalates, cyanide, and a variety of metals. Metal

production and fabrication, currently takes place in the Burgard Industrial Park and several sites in the RM 8 to 10.3W reach. COIs associated with metal production and fabrication include metals, PAHs, and TPH. Hydraulic oil with PCBs was often used for high-temperature applications such as die-casting machines. Metal plating also has occurred at a few locations in the Study Area, including Columbia American Plating at RM 9.5W. COIs associated with metal plating activities include VOCs, PAHs, TPH, cyanide, and several metals.

- **Manufactured Gas Production.** Manufactured gas production operations took place between 1913 and 1956 at Portland Gas & Coke (RM 6.2W). The Pintsch Compressing Company Gas Works operated between 1890 and the mid-1930s at RM 7.3W and manufactured compressed gas from crude oil for railroad train lighting. Prior to 1913, gas production also occurred just upstream of the Study Area at the Portland MGP site at RM 12.2E. COIs associated with manufactured gas operations include VOCs, SVOCs, TPH, PAHs, metals, and cyanide.
- **Electrical Production and Distribution.** Electrical transformers and capacitors are associated with all of the major industries in the harbor. Some of these transformers and capacitors may contain PCBs. Seven current and one historical substation are found in the Study Area. Transformer repair, servicing, and salvaging operations were found on the east bank from RM 11.3 to 11.5 (Tucker Building, Westinghouse, and PacifiCorp Albina Properties), at RM 3.7W (ACF Industries), RM 9.5E (Portable Equipment Salvage), RM 9.5W (GE Decommissioning), and the GE facility at NW 28th Ave (TSCA site). COIs linked with these types of operations include PAHs, TPH, and PCBs.
- **Bulk Fuel Distribution and Storage and Asphalt Manufacturing.** Bulk fuel facilities have a long history in Portland Harbor. By 1936, most of the facilities currently in place had been established between RM 4 and 8 on the west side of the river. COIs typically associated with bulk fuel storage operations include VOCs, SVOCs, PAHs, TPH, and metals.
- **Steel Mills, Smelters, and Foundries.** Several foundries were located within the Study Area, at RM 11.4W (Gender Machine Works), RM 9.7W (Schmitt Forge), and RM 2.7E (Consolidated Metco). Smelters were located at RM 7.2W (Gould), RM 9W (National Lead/Magnus Smelter), and RM 11.6W (RiverTec Property). Steel mills are or were located at RM 2.4E (Evraz, aka Oregon Steel Mill) and at RM 8.3W (former Oregon Steel Mill operation at Front Ave LP). COIs associated with these types of operations include metals, TPH, PCBs, and PAHs. PCBs were a component of hydraulic fluid for high temperature applications (machining and die casting) where fire resistance was important, and were also a component of heat transfer fluid used in applications like heat exchangers and recirculating cooling systems.
- **Commodities Maritime Shipping and Associated Marine Operations.** In addition to the Port of Portland's large presence in Portland Harbor with three

deep-water terminals committed to import/export, currently there are or have been several other commodity shipping facilities in the harbor (Map 3.2-11). These include the grain handling operations at CDL Pacific Grain (RM 11.4E) and Centennial Mills (RM 11.3W), edible oils at the former Premier Edible Oils facility (RM 3.6E), scrap metal export at International Terminals (RM 3.7E), cement import and distribution at Glacier NW (RM 11.3E), anhydrous ammonia and solid and granular urea at JR Simplot in the South Rivergate Industrial Park (RM 3E), and alumina, electrode binder pitch, and grain at the former Goldendale Aluminum property (RM 10E). Supporting maritime activities include over-water tug and barge moorage, maintenance and repair facilities, overwater bunkering and lightering, tug-assisted and independent maneuvering of vessels in and around marine facilities, and stevedoring (loading and discharging) product at vessels. Incidental spills into the river from commodities maritime shipping include organic materials, VOCs, PAHs, and TPH.

- **Rail Yards.** Rail yard and freight car repair facilties operated at several locations within the Study Area. Active facilities are located at approximately RM 9.8 to 11.1E (UPRR Albina Yard), RM 8.6 to 9.5W (PTRR Guilds Lake Yard), and RM 4.8E (UPRR – St. Johns Tank Farm). Historical rail yard operations were located at and around RM 11.6W (BNSF Hoyt Street Railyard, and UPRR Union Station operations). Historical rail car maintenance operations were located at RM 3.6 (ACF Industries). COIs may include VOCs, SVOCs, TPH, PCBs, and metals.

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Contaminant migration to in-water media occurs through several migration pathways, including stormwater, industrial wastewater, overland flow, groundwater, bank erosion, and overwater releases. Contaminated surface soils in upland areas and along riverbanks can be carried directly to the river as riverbank erosion and in stormwater runoff, particularly during high flows and floods. In some locations, contaminated dredged material may have been placed in low-lying areas subject to erosion. While the quality of this fill material is generally undocumented, because of the history of sediment contamination from industrial and maritime sources, contaminated sediment could have been included in fill material.

Migration of contaminants from upland areas to the river via groundwater is a historical source of contamination to the river at a limited number of upland sites within the Study Area. At a subset of these sites, the historical groundwater pathway has contributed significant loading of upland contaminants to sediment and TZW. While some complete historical groundwater transport pathways have been mitigated or eliminated through source control actions, others remain complete, as identified in Section 10.1.3.2 below.

Overwater releases were likely common occurrences at industries that relied on maritime shipping and located on the banks of the Willamette River, and are likely important historical contributors to in-water contamination. However, prior to the relatively recent enactment of reporting requirements, overwater spills were generally undocumented.

Upstream sources also contributed to the historical contamination of the lower Willamette River. These sources included sewerage, stormwater runoff, and direct discharge of industrial wastes from upstream cities, towns, and industrial areas; agricultural runoff; and aerial deposition on the water surface and drainage areas within the Willamette Valley.

10.1.3.2 Current

Many of the large industrial operations in the harbor noted above have ceased operating over the past 50 years. Operations that continue to exist today include bulk fuel storage, barge building, ship repair, automobile scrapping, recycling, steel manufacturing, cement manufacturing, transformer reconditioning, operation and repair of electrical transformers (including electrical substations), and many smaller industrial operations. Locations of both current and historical major industrial operations in Portland Harbor are presented on Maps 3.2-3 through 3.2-12.

Stormwater and wastewater discharges are regulated and permitted for many of the sites adjacent to the Study Area. However, sampling for RI-related chemicals in stormwater and catch basins only began in recent years and, for the most part, has only been done for those facilities that have voluntarily conducted a stormwater source control evaluation. With the construction of stormwater treatment systems and wastewater treatment systems over the years, overland transport has been largely abated at most sites. A current likely complete overland transport pathway has been identified ~~as likely complete~~ at very few sites.

Current known complete or likely complete groundwater pathways have been identified at 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. The groundwater pathway assessment conducted during the RI consisted of detailed groundwater discharge and TZW sampling ~~information~~ at nine high priority sites. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, groundwater migration was found to have no significant influence at four other ~~additional~~ sites, and groundwater effects could not be determined~~established~~ at one site (see Appendix C2).

Riverbank erosion from contaminated and unstabilized bank areas may represent an ongoing release mechanism in the Study Area. Currently about 75 percent of the riverbanks within the Study Area are stabilized and armored with various materials, including seawalls, riprap, and engineered and non-engineered soil. Known or likely complete riverbank pathways have been identified at a few sites with unstabilized banks.

The activities most commonly associated with current overwater spills in the Study Area are product handling, overwater activities such as refueling, and spills from vessels. Overwater releases are likely important contributors to in-water contamination at sites that have long histories of overwater operations and product transfers. Spill records collected over the past approximately 30 years do not generally record large releases, but there have been some exceptions.

DEQ's JSCS program focuses on the abatement of current and threatened future releases of contaminants to the Study Area. The current status of that program is summarized in Section 4.6.

As with historical sources, current upriver sources also play a role in the contaminant distribution in the LWR. Current upstream loading is discussed in the following section.

10.1.4 Loading, Fate and Transport

This section summarizes the information detailed in Section 6 of the RI on contaminant mass inputs and internal mass transfer mechanisms within the Study Area on a site-wide basis. A comparision of the relative magnitude of these terms is presented for each indicator contaminant in Section 10.2. External loads include upstream loading via surface water and sediment bedload, stormwater, permitted industrial discharges, upland groundwater transport, atmospheric deposition, upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases. ~~A comparision of the relative magnitude of these terms is presented for each indicator contaminant in Section 10.2.~~

Upstream loading represents the largest current contaminant loading term for the Study Area. While upstream surface water and suspended sediment concentrations are typically lower than those measured in the Study Area, the very large flow volume of the river compared to the flow volumes for the other loading terms results in a relatively large mass load of contaminants compared to other current sources. With the exception of total PAHs and TBT, upstream loading is greater than other loading terms by 1 to 3 orders of magnitude for all of the indicator contaminants. Estimated flow volumes used for the various loading terms are preseted on Figure 10.1-3.

Stormwater runoff is the second largest quantified annual external loading term to the Study Area for all indicator chemicals except total PAHs and arsenic (dioxins/furans and TBT were not sampled in stormwater). Loading from CSO discharges is also a factor. Contaminants present in stormwater runoff are transported mostly via conveyance systems and discharged through numerous outfalls along the river shoreline within the Study Area. Overland flow of stormwater to the river also occurs in some relatively limited areas.

The other external loading mechanisms (permitted discharges, groundwater transport, atmospheric deposition, direct upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases) are generally lower in

Commented [AE11]: If the relative magnitudes are presented in 10.2, why are they discussed here

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magnitude than the upstream and stormwater loading. Where notable, the other mechanisms are discussed on a contaminant-specific basis in Section 10.2

Internal transfer mechanisms involve the transport of contaminant mass from one media to another within the Study Area, but do not add new contaminant mass to the Study Area. Internal fate and transport mechanisms include sediment resuspension, transport, and deposition, solid/aqueous-phase partitioning, abiotic/biotic transformation and degradation, biological uptake and depuration, and partitioning from surface sediment to surface water. Due to the ~~general~~ hydrophobic nature of most of the organic containinats found in the Study Area, they tend to preferentially partition to the dissolved and particulate organic matter. As that represents the largest available pool of organic carbon in the Study Area, contaminated sediments represent the largest by mass of contaminants in the system.

Commented [Int14]: This sentence was retained in EPA's July RL/SO, it has been moved here to the internal transfer mechanism subsection.

Lateral and vertical movement of chemicals in surface water occurs primarily as a result of turbulent (eddy) dispersion (mechanical mixing). Higher flow velocities typically cause greater mixing and increased transport of suspended and bedload sediments. Relevant processes that influence sediment transport include deposition, erosion/resuspension, mixed-layer turbation, long-term burial, and ingestion/uptake by biota. The relative significance of these transport and fate mechanisms varies by contaminant, depending on source locations and the chemical-specific other physical/chemical properties. A potentially important mass transfer mechanism is surface sediment resuspension and movement of contaminants from bedded sediment to the water column with a resultant increase in mobility and bioavailability. Abiotic and degradation processes relevant for transformation and degradation of contaminants in the Study Area include abiotic oxidation/reduction, hydrolysis, dehalogenation, volatilization (primarily from dissolved phase in surface water), and photolysis (primarily in upper levels of surface water). Biodegradation involves the metabolic oxidation or reduction of organic compounds and is carried out predominantly by bacteria in aqueous environments.

Finally, a number of processes govern how organisms living in the Study Area are exposed to contaminants and how contaminants are transformed, excreted, or stored in tissue. Organisms living in the Study Area may bioaccumulate contaminants through physical, chemical, and biological processes, including transfer of water-borne contaminants across gill structures or other tissues, ingestion of sediment, or consumption of prey, which may increase relative tissue concentrations at progressively higher trophic levels in the food chain. Contaminant burden in body tissues is mediated through growth, reproduction, excretion, metabolic transformation, or sequestration.

10.1.5 Human and Ecological Receptors, Exposure Pathways, and Summary of Site Risks

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People interact with the river in a number of ways. Portland Harbor is a major industrial water corridor and working harbor, and the majority of the Study Area waterfront is currently zoned for industrial land use (City of Portland 2006b). The Study Area also contains some natural areas and provides recreational opportunities, both on the water and along the riverbanks, including boat ramps, beaches, and waterfront parks. Recreational fishing is conducted throughout the LWR basin and in the Study Area, both by boaters and from shore. The extent to which commercial fishing occurs within the Study Area is not known, but it is presumed to be negligible. For Native American anglers, the Willamette River provides a ceremonial and subsistence fishery for Pacific lamprey and spring Chinook salmon. There is also documented evidence of transients camping along the river for extended periods of time.

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Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the Study Area, and include populations who may be exposed to contamination though a variety of activities. The specific populations and exposure pathways evaluated were:

- Dockside workers — direct exposure via incidental ingestion and dermal contact with beach sediments.
- In-water workers — direct exposures to in-water sediment.
- Transients — direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps.
- Recreational beach users — direct exposure to beach sediment and surface water while for swimming.
- Tribal fishers — direct exposure to beach or in-water sediments, and consumption of migratory and resident fish.
- Recreational and subsistence fishers — direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish.
- Divers — direct exposure to in-water sediment and surface water.
- Domestic water user — direct exposure to untreated surface water potentially used as a drinking water source in the future.
- Infants - consumption of human breast milk. ~~to~~

The major findings of the BHHRA are:

- Estimated cancer risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment and surface water. Risks and noncancer hazards from fish and shellfish consumption exceed the EPA point of departure for cancer risk of 1 x 10^{-4} and target hazard index (HI) of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile. Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated RME cancer risks are 4 x 10^{-3} and 1 x 10^{-2} for recreational and subsistence fishers, respectively.

- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Based on a harbor-wide evaluation of noncancer risk, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates for recreational fishers are at RM 4, RM 7, RM 11, and in Swan Island Lagoon.

  The highest noncancer hazards are associated with nursing infants of mothers, who consume resident fish from Portland Harbor. When fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for breastfed infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME HI for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding HI estimates for nursing infants of mothers, who consume fish, are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.

- PCBs are the primary contributor to risk from fish consumption harbor-wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates, particularly at RM 6 and 7. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

From an ecological habitat perspective, the majority of the Study Area is industrialized, with modified shoreline and nearshore areas (e.g., wharfs, piers extending out toward the channel, bulkheads, and riprap-armored banks). The federal navigation channel has less habitat diversity than the shallow, nearshore areas, but this is consistent with river systems generally. Some segments of the Study Area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing some habitat for a suite of local fauna. Riparian, shallow-water, and vegetated habitats are limited to the nearshore area or shoreline, and are much less extensive.

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Organisms that use the lower Willamette River include invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group contributes to the ecological function of the river based on trophic level, abundance, biomass, and interaction with the physical-chemical environment and other species. The lower Willamette River is an important migration corridor for anadromous fish, such as salmon and lamprey, and provides habitat for numerous resident fish species (more than 40 species have been collected in many historical and recent studies) that represent four feeding guilds: herbivores, invertivores (either from the water column or bottom habitats), piscivores, and detritivores. A number of species are omnivores and utilize multiple food types.

Habitat in the Study Area is limited for semi-aquatic mammals because of past human modification of riparian habitats. The upland environment near the LWR is primarily urban, with fragmented areas of riparian forest, wetlands, and associated upland forests. Numerous aquatic and shorebird species, such as cormorants and spotted sandpipers, use the habitats, where available, in the Study Area.

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates** – Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW
- **Fish** – Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals** – Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants** – Direct contact with surface water and shallow TZW.

The following presents the primary conclusions of the BERA.

- In total, 93 contaminants (as individual contaminants, sums, or totals) pose potentially unacceptable ecological risk. The list can be condensed if individual PCB, DDx and PAH compounds or groups are condensed into three comprehensive groups: total PCBs, total DDx, and total PAHs. Doing so reduces the number of contaminants posing potentially unacceptable risks to 66.

- Risks to benthic invertebrates are clustered in 17 benthic areas of concern (AOCs).

- Sediment and TZW samples with the highest HQs for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.

- COPCs in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations are PAHs and DDx compounds.

- The most ecologically significant contaminants are PCBs, PAHs, dioxins and furans (as toxic equivalent [TEQ]), and DDT and its metabolites. PAHs and DDx risks are largely limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.

- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey. The PCB TEQ fraction of the total TEQ is responsible for the majority of total TEQ exposure, but the total dioxin/furan TEQ fraction also exceeds its TRV in some locations of the Study